Issued on: February 3, 2006.

Stephen R. Kratzke,

Associate Administrator for Rulemaking.

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DEPARTMENT OF THE INTERIOR

Fish and Wildlife Service

50 CFR Part 17

Endangered and Threatened Wildlife and Plants; Petition To List the Polar Bear as Threatened

AGENCY: Fish and Wildlife Service, Interior.

ACTION: Notice of 90-day petition finding and initiation of status review.

SUMMARY: We, the U.S. Fish and Wildlife Service (Service), announce a 90-day finding on a petition to list the polar bear (*Ursus maritimus*) as threatened under the Endangered Species Act of 1973, as amended (Act). We find that the petition presents substantial scientific or commercial information indicating that the petitioned action of listing the polar bear may be warranted. We, therefore, are initiating a status review of the polar bear to determine if listing under the Act is warranted. To ensure that the status review is comprehensive, we are soliciting scientific and commercial information regarding this species.

DATES: We must receive your comments on or before April 10, 2006.

ADDRESSES: If you wish to comment, you may submit your comments and/or information concerning this species and the status review by any one of the following methods:

1. You may submit written comments and information to the Supervisor, U.S. Fish and Wildlife Service, Marine Mammals Management Office, 1011 East Tudor Road, Anchorage, Alaska 99503.

2. You may hand-deliver written comments to our office at the address given above.

3. You may send your comments by electronic mail (e-mail) directly to the Service at *AK_Polarbear@fws.gov,* or to the Federal eRulemaking Portal at *http://www.regulations.gov.* Your submission must include "Attn: Polar Bear" in the beginning of your message, and you must not use special characters or any form of encryption. Electronic attachments in standard formats (such as .pdf or .doc) are acceptable, but please name the software necessary to open any attachments in formats other than those given above. Also, please include your name and return address in your e-mail message. If you do not receive a confirmation from the system that we have received your e-mail message, please submit your comments in writing using one of the alternate methods described above. In the event that our Internet connection is not functional, please submit your comments by one of the alternate methods mentioned above.

FOR FURTHER INFORMATION CONTACT: Scott Schliebe (see **ADDRESSES**), telephone, 907–786–3800; facsimile, 907–786–3816.

SUPPLEMENTARY INFORMATION:

Public Comments Solicited

We intend that any final action resulting from this status review will be as accurate and as effective as possible. Therefore, we solicit comments or suggestions from the public, concerned governmental agencies, the scientific community, industry, or any other interested party. We are opening a 60-day public comment period to allow all interested parties an opportunity to provide information on the status of the polar bear throughout its range, including:

(1) Information on taxonomy, distribution, habitat selection (especially denning habitat), food habits, population density and trends, habitat trends, and effects of management on polar bears;

(2) Information on the effects of climate change and sea ice change on the distribution and abundance of polar bears and their principal prey over the short- and long-term;

(3) Information on the effects of other potential threat factors, including oil and gas development, contaminants, hunting, poaching, and changes of the distribution and abundance of polar bears and their principal prey over the short and long term;

(4) Information on management programs for polar bear conservation, including mitigation measures related to oil and gas exploration and development, hunting conservation programs, anti-poaching programs, and any other private, tribal, or governmental conservation programs which benefit polar bears, and

(5) Information relevant to whether any populations of the species may qualify as distinct population segments.

We will base our finding on a review of the best scientific and commercial information available, including all information received during the public comment period.

Our practice is to make comments, including names and home addresses of respondents, available for public review during regular business hours. Individual respondents may request that we withhold their home addresses from the record, which we will honor to the extent allowable by law. There also may be circumstances in which we would withhold from the record a respondent's identity, as allowable by law. If you wish us to withhold your name and/or address, you must state this prominently at the beginning of your comment. However, we will not consider anonymous comments. We will make all submissions from organizations or businesses, and from individuals identifying themselves as representatives or officials of organizations or businesses, available for public inspection in their entirety.

All comments and materials received will be available for public inspection, by appointment, during normal business hours at our Anchorage, Marine Mammals Management Office (see **ADDRESSES**).

Background

We received a petition from the Center for Biological Diversity dated February 16, 2005, to list the polar bear as threatened throughout its range with critical habitat in the United States. The petition, which was clearly identified as such, contained detailed information on the natural history and biology of the polar bear, and the current status and distribution of the species. It also contained information on what they reported as potential threats to the species from climate change, oil and gas development, contaminants, hunting, and poaching. The petition also discussed existing regulatory mechanisms and their perceived inadequacy. In a letter dated July 5, 2005, the petitioners informed us that two additional parties were joining as petitioners: The Natural Resources Defense Council and Greenpeace, Inc. In the same letter, the petitioners informed us of two new scientific articles, Henson *et al.* 2005, and Stroeve *et al.* 2005, that they wanted us to take into consideration when conducting our evaluation on the petition to list the polar bear. The petitioner further submitted new information in a letter received on December 27, 2005, to be considered, along with the information in the initial petition, in making our 90-day finding.

Subsequent to the filing of the initial petition with the Service, a petitioner may submit additional information relevant to the petitioned action. If the petitioner requests that the Service consider the information in making the 90-day finding on the petition, the Service will treat the new information, together with the information in the initial petition, as a new petition filed on the date that the new information is received. In such case, the Service will consider the initial petition to be withdrawn by the petitioner. This has the effect of "resetting the clock" for the purpose of calculating the statutory deadlines under section 4(b)(3) of the Act. Applying this reasoning to the Center for Biological Diversity's petition regarding the polar bear, we consider the petition to have been received on December 27, 2005.

On the basis of information provided in the petition we have determined that the petition presents substantial scientific or commercial information that listing the polar bear as threatened may be warranted. Therefore, we are initiating a status review to determine if listing the species is warranted. To ensure that the status review is comprehensive, we are soliciting scientific and commercial information regarding this species. Under section 4(b)(3)(B) of the Act, we are required to make a finding as to whether listing the polar bear is warranted by December 27, 2006.

The petitioners also requested that critical habitat be designated for this species. We always consider the need for critical habitat designation when listing species. If we determine in our 12-month finding that listing the polar bear is warranted, we will address the designation of critical habitat in a subsequent proposed rule.

Author

The primary author of this document is Scott Schliebe, Polar Bear Project Leader, Marine Mammals Management Office, U.S. Fish and Wildlife Service, Anchorage, Alaska.

Authority: The authority for this action is the Endangered Species Act of 1973 as amended (16 U.S.C. 1531 *et seq.*).

Dated: February 3, 2006.

H. Dale Hall,

Director, U.S. Fish and Wildlife Service.

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The Challenge of Long-Term Climate Change

K. Hasselmann,[1,2*] M. Latif,[3] G. Hooss,[4] C. Azar,[5] O. Edenhofer,[1,6] C. C. Jaeger,[1,6] O. M. Johannessen,[1,7] C. Kemfert,[1,4] M. Welp,[1,6] A. Wokaun[1,8]

Climate policy needs to address the multidecadal to centennial time scale of climate change. Although the realization of short-term targets is an important first step, to be effective climate policies need to be conceived as long-term programs that will achieve a gradual transition to an essentially emission-free economy on the time scale of a century. This requires a considerably broader spectrum of policy measures than the primarily market-based instruments invoked for shorter term mitigation policies. A successful climate policy must consist of a dual approach focusing on both short-term targets and long-term goals.

There is widespread consensus in the climate research community that human activities are changing the climate through the release of greenhouse gases, particularly CO_2, into the atmosphere (*1*, *2*). Because of the considerable inertia of the climate system—caused by the long residence times of many greenhouse gases in the atmosphere, the large heat capacity of the oceans, and the long memory of other components of the climate system, such as ice sheets and the biosphere—human modifications of the climate system through greenhouse gas emissions are likely to persist for many centuries in the absence of appropriate mitigation measures (*2*).

A common response to the uncertain risks of future climate change is to develop climate policy as a sequence of small steps. The Kyoto protocol, once enacted, will commit the signatories to a nominal reduction of greenhouse gas emissions by 5% between 2008 and 2012, relative to 1990. The protocol is a historic first step toward reversing the trend of continually increasing greenhouse gas emissions and will provide valuable experience in the application of various mitigation instruments such as tradable emission permits. However, a nominal emission reduction of only 5% by a subset of the world's nations will have a negligible impact on future global warming. To avoid major long-term climate change, average per capita greenhouse gas emissions must be reduced to a small fraction of the present levels of developed countries on the time scale of a century (*2*). Such reductions cannot be achieved by simply extrapolating short-term policies but require a broader spectrum of instruments.

Most investigations (*2–4*) and public attention have focused on the projected climate change in this century. A potentially far more serious problem, however, is the global warming anticipated in subsequent centuries if greenhouse gas emissions continue to increase unabated (Fig. 1, left panels) (*5–7*). The projected temperature and sea level changes for the next millennium greatly exceed those in the next hundred years (Fig. 1, yellow boxes). If all estimated fossil fuel resources are burnt, CO_2 concentrations between 1200 parts per million (ppm) (scenario C in Fig. 1) and 4000 ppm (scenario E in Fig. 1) are predicted in the second half of this millennium, leading to temperature increases of 4°C to 9°C and a sea level rise of 3 to 8 m. Predictions of this magnitude are beyond the calibration ranges of climate models and must therefore be treated with caution (*8*). However, the predicted climate change clearly far exceeds the natural climate variability (~1°C to 2°C) experienced in the past 10,000 years. Even if emissions are frozen at present levels, the accumulated emissions over several centuries still yield climate change on the order of the lower business-as-usual (BAU) scenario C.

Major climate change can be avoided in the long term only by reducing global emissions to a small fraction of present levels within one or two centuries. As an example, we have computed optimal CO_2 emissions paths that minimize the time-integrated sum of climate damage and mitigation costs, using an integrated assessment model consisting of a nonlinear impulse response climate model (*7*) coupled to an elementary economic model (*9*) (Fig. 1, right panels). Cost-benefit analyses depend on many controversial assumptions, such as the role of economic inertia (included in case a, ignored in case b), the impact of declining costs for new technologies, and the discount factors applied to future climate change mitigation and adaptation costs (*10–14*). However, the resultant long-term climate change is insensitive to the details of the optimal emission path (compare curves a and b), provided the emissions are sufficiently reduced. Because of the long residence time of CO_2 in the atmosphere (>100 years), the climatic response is governed by the cumulative CO_2 emissions rather than by the detailed path.

The impact of the Kyoto agreement (k in Fig. 1, right panels) is hardly discernible on the millennial time scale, suggesting that the Kyoto debate should focus on the long-term implications of the protocol rather than on its short-term effectiveness. The Kyoto targets may not be met by some countries and may be exceeded by others. Important in either case is that the Kyoto policy is accompanied by measures that ensure continuing reductions in subsequent decades.

Because of the 10-year horizon of the Kyoto protocol, climate policy has tended to focus on promoting mitigation technologies that are currently most cost-effective, such as wind energy, biomass fuels, fuel switching from coal and oil to gas, and improved energy efficiency in transportation, buildings, and industry. In the short to medium term, the combined mitigation potential of these technologies is substantial: It has been estimated that, if fully implemented, they could halve global greenhouse gas emissions relative to the BAU level within two decades (*4*). The market-based instruments (such as tradable emission permits and tax incentives) used to meet the more modest 5% Kyoto reduction targets will accelerate the penetration of these technologies into the marketplace but will be inadequate to realize the full potential of these technologies.

Yet, even if forcefully implemented, currently available low-cost technologies have limited capacity for substantial global emission reduction and will not be able to counter the rising emissions projected for the long term. Future emissions will be driven mainly by the expanding populations of the developing world, which strive to achieve the same living standards as the industrial countries. An emissions reduction of 50% applied to a projected BAU increase in this century by a factor of four (*2–4*) still leads to a doubling of emissions, far from the long-term target of near-zero emissions. Furthermore, the mitigation costs for today's technologies are estimated to rise rapidly if per capita emissions are reduced by more than half (*4*). Thus, although the Kyoto protocol will

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boost technologies that are cost-effective in the short term, further emission reductions in the post-Kyoto period could be limited by prohibitive costs. Without affordable new technologies capable of higher global emission reductions, stricter emission reduction targets will be considered impossible to meet and will not be adopted.

Although no such technology is yet economically competitive, there exist many promising candidates (*15*, *16*), ranging from solar thermal or photovoltaic energy—in combination with hydrogen technology—to carbon sequestration in geological formations or the ocean (*17–20*), advanced nuclear fission, and nuclear fusion (*4*, *15*, *16*). Which technology, or mix of technologies, will ultimately prove most cost-effective cannot be predicted. We will need to accept these uncertainties and support a number of competing technologies in order to have available several commercially viable alternatives when the large-scale transition to low-emission technologies becomes more urgent.

Although short-term climate policy can be formulated in terms of emission targets and implemented with instruments that internalize the costs incurred by climate change ("polluter-pays principle"), long-term climate policy will require a broader spectrum of measures extending well beyond the traditional horizon of government policies or business investment decisions. The entry of new technologies into the marketplace depends on multiple incentives and feedbacks, including private investments; government investments in infrastructure and subsidies for pilot plants; protected niche markets; and changes in consumer preferences and lifestyles (*21–23*). Climate is a public good that demands communal action for its protection, including the involvement of citizens and institutions such as the media that shape long-term public attitudes. Self-interest alone will not motivate businesses and the public to change established practices and behavioral patterns. The goal of long-term climate policy must be to influence business investments, research, education, and public perceptions such that stringent emission-reduction targets—although not attainable today—become acceptable at a later time.

Although major changes are necessary, the long time scales of the climate system allow a gradual transition (*24*, *25*). Estimated costs to halve global emissions range from ~1 to 3% of gross domestic product (GDP) (*4*), similar to the annual GDP growth rate in many countries. Thus, implementation of an effective climate policy over a time period of, say, 50 years would delay economic growth by only about a year over the same period (*26*). This appears to be an acceptable price for avoiding the risks of climate change. However, because the global political-economic system exhibits considerable inertia, a transition to a sustainable climate can be achieved without major socioeconomic dislocations only if the introduction of appropriate measures addressing the long-term mitigation goals is not delayed.

Science can assist the development of long-term climate policies by providing detailed analyses of the technological options and their implications for national economies and global development. The Intergovernmental Panel on Climate Change (IPCC) has played a pivotal role in the climate debate by presenting authoritative reviews of the state of science and on climate change impact, mitigation, and policy. Similar expertise should be made available to climate negotiators in the form of timely analyses of the implications of alternative climate policy regimes for the individual signatories of the United Nations Framework Convention on Climate Change. Although binding long-term commitments cannot be expected from governments, declarations of long-term policy goals and visible actions to achieve these goals are essential for the investment plans of businesses, particularly for energy technologies characterized by long capital lifetimes. A long-term perspective is equally important for the public, who must understand and support the policies. Binding commitments to meet short-term emission-reduction targets must therefore go hand in hand with clearly defined strategies to achieve substantially more stringent reductions in the longer term.

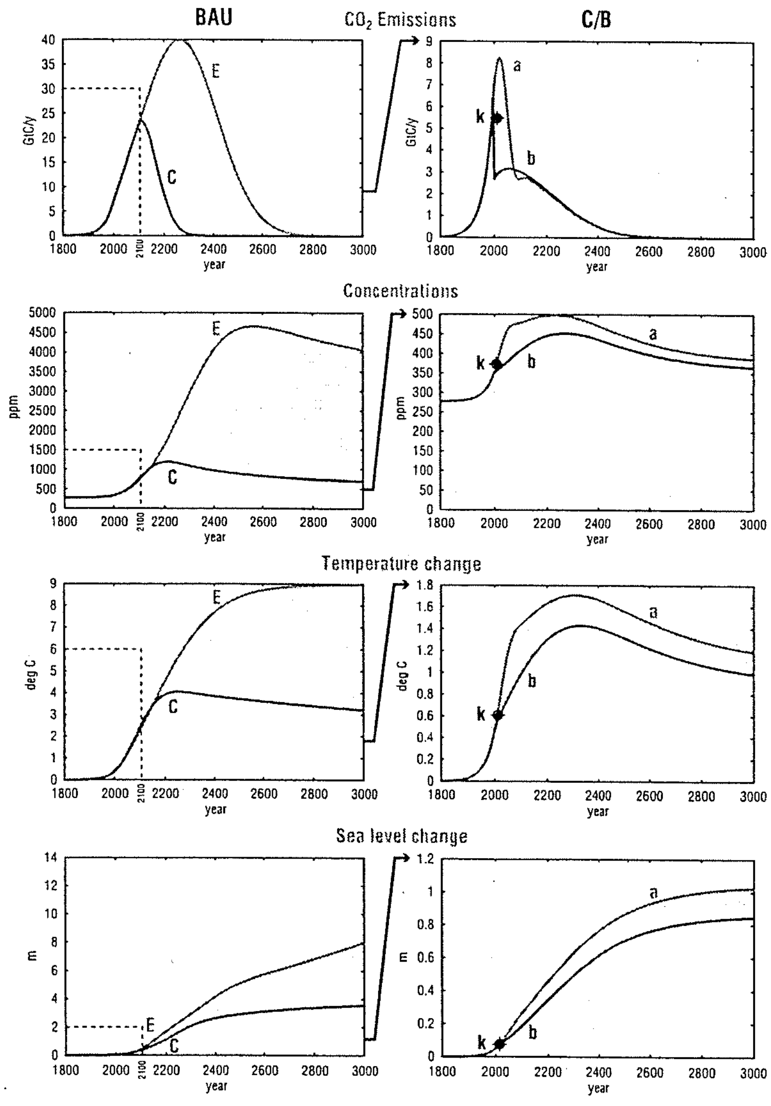

Fig. 1. CO_2 emissions and concentrations, global mean near surface temperature, and global mean sea level for business-as-usual (BAU) emission scenarios (**left**) and optimized cost/benefit (C/B) trajectories (**right**; note change of scale). The BAU scenarios assume that all fossil fuel resources, ranging from 4000 gigatons of carbon (GtC) (conventional resources, C) to 15,000 GtC (conventional plus exotic resources, E), are used. The sea level rise represents the sum of thermal expansion of the warming ocean, the melting of smaller inland glaciers, and the slow melting of the Greenland Ice Sheet (*1*). Inclusion of other greenhouse gases could increase the peak values by ~10 to 20%. The cost/benefit solutions include (a) or ignore (b) economic inertia. Pronounced differences between these cases in the short term have little impact on long-term climate. The impact of the Kyoto period (k) is not discernible on these multicentennial time scales.

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30. The views expressed in this article evolved from discussions with members and guests of the European Climate Forum (ECF). We acknowledge constructive comments from G. Berz, C. Carraro, B. Eliasson, J. Engelhard, J. Gretz, B. Hare, J.-C. Hourcade, M. Hulme, M. Mcfarland, N. Otter, H.-J. Schellnhuber, S. Singer, and S. C. Peck. However, ECF does not endorse specific views expressed by its members, and this article does not represent an ECF consensus view.

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VIEWPOINT

Climate Change: The Political Situation

Robert T. Watson

Human-induced climate change is one of the most important environmental issues facing society worldwide. The overwhelming majority of scientific experts and governments acknowledge that there is strong scientific evidence demonstrating that human activities are changing the Earth's climate and that further human-induced climate change is inevitable. Changes in the Earth's climate are projected to adversely affect socioeconomic systems (such as water, agriculture, forestry, and fisheries), terrestrial and aquatic ecological systems, and human health. Developing countries are projected to be most adversely affected, and poor people within them are the most vulnerable. The magnitude and timing of changes in the Earth's climate will depend on the future demand for energy, the way it is produced and used, and changes in land use, which in turn affect emissions of greenhouse gases and aerosol precursors.

The most comprehensive and ambitious attempt to negotiate binding limits on greenhouse gas emissions is contained in the 1997 Kyoto Protocol, an agreement forged in a meeting of more than 160 nations, in which most developed countries agreed to reduce their emissions by 5 to 10% relative to the levels emitted in 1990. Although the near-term challenge for most industrialized countries is to achieve their Kyoto targets, the long-term challenge is to meet the objectives of Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC), i.e., stabilization of greenhouse gas concentrations in the atmosphere at levels that would prevent dangerous anthropogenic interference with the climate system, with specific attention being paid to food security, ecological systems, and sustainable economic development. To stabilize the atmospheric concentration of carbon dioxide requires that emissions eventually be reduced to only a small fraction of current emissions, i.e., 5 to 10% of current emissions.

All major industrialized countries except the United States, the Russian Federation, and Australia have ratified the Kyoto Protocol. The United States and Australia have publicly stated that they will not ratify it, and statements from the Russian Federation are contradictory. Russian ratification is essential for the Kyoto Protocol to enter into force.

The United States has stated that the Kyoto Protocol is flawed policy for four reasons:

1) There are still considerable scientific uncertainties. However, although it is possible that the projected human-induced changes in climate have been overestimated, it is equally possible that they have been underestimated. Hence, scientific uncertainties, as agreed by the governments under Article 3 of the UNFCCC, are no excuse for inaction (the precautionary principle).

2) High compliance costs would hurt the U.S. economy. This is in contrast to the analysis of the Intergovernmental Panel on Climate Change (IPCC), which estimated that the costs of compliance for the United States would be between US$14 and US$135 per ton of carbon avoided with international carbon dioxide emissions trading (a 5-cents-per-gallon gasoline tax would be equivalent to US$20 per ton of carbon). These costs could be further reduced by the use of carbon sinks, by carbon trading with developing countries, and by the reduction of other greenhouse gas emissions.

3) It is not fair, because large developing countries such as India and China are not obligated to reduce their emissions. However, fairness is an equity issue. The parties to the Kyoto Protocol agreed that industrialized countries had an obligation to take the first steps to reduce their greenhouse gas emissions, recognizing that ~80% of the total anthropogenic emissions of greenhouse gases have been emitted from industrialized countries (the United States currently emits ~25% of global emissions); that per capita emissions in industrialized countries far exceed those from developing countries; that developing countries do not have the financial, technological, or institutional capability of industrialized countries to address the issue; and that increased use of energy is essential for poverty alleviation and long-term economic growth in developing countries.

4) It will not be effective, because developing countries are not obligated to reduce their emissions. It is true that long-term stabilization of the atmospheric concentration of greenhouse gases cannot be achieved without global reductions, especially given that most

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South America, because of the economic growth there, would make global air quality more of an issue in the Southern Hemisphere, a region where only biomass burning has been considered important so far.

Finally, the importance of megacities as sources of regional and global pollution is worth noting. Megacities may be defined as metropolitan areas with over 10 million inhabitants, although there is no precise accepted threshold, and population estimates are not necessarily based on the same areas of reference. In 2001, there were 17 megacities according to United Nations statistics (*47*). With rapid growth of the world's population, particularly in developing countries, and continuing industrialization and migration toward urban centers, megacities are becoming more important sources of air pollution from associated mobile and stationary sources. Air quality in megacities is thus of great concern, as illustrated by a study in Mexico City (*48*). Although the health effects of air pollution on the inhabitants of megacities are a serious social problem, its regional and global environmental consequences are also of great concern. Therefore, local, regional, and global air-quality issues, and regional and global environmental impacts, including climate change, should be viewed in an integrated manner.

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Modern Global Climate Change

Thomas R. Karl[1] and Kevin E. Trenberth[2]

Modern climate change is dominated by human influences, which are now large enough to exceed the bounds of natural variability. The main source of global climate change is human-induced changes in atmospheric composition. These perturbations primarily result from emissions associated with energy use, but on local and regional scales, urbanization and land use changes are also important. Although there has been progress in monitoring and understanding climate change, there remain many scientific, technical, and institutional impediments to precisely planning for, adapting to, and mitigating the effects of climate change. There is still considerable uncertainty about the rates of change that can be expected, but it is clear that these changes will be increasingly manifested in important and tangible ways, such as changes in extremes of temperature and precipitation, decreases in seasonal and perennial snow and ice extent, and sea level rise. Anthropogenic climate change is now likely to continue for many centuries. We are venturing into the unknown with climate, and its associated impacts could be quite disruptive.

The atmosphere is a global commons that responds to many types of emissions into it, as well as to changes in the surface beneath it. As human balloon flights around the world illustrate, the air over a specific location is typically halfway around the world a week later, making climate change a truly global issue.

Planet Earth is habitable because of its location relative to the sun and because of the natural greenhouse effect of its atmosphere. Various atmospheric gases contribute to the greenhouse effect, whose impact in clear skies is ~60% from water vapor, ~25% from carbon dioxide, ~8% from ozone, and the rest from trace gases including methane and nitrous oxide (*1*). Clouds also have a greenhouse effect. On average, the energy from the sun received at the top of the Earth's atmosphere amounts to 175 petawatts (PW) (or 175 quadrillion watts), of which ~31% is

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even stronger events when precipitation amounts increase (*16–18*).

There is considerable uncertainty as to exactly how anthropogenic global heating will affect the climate system, how long it will last, and how large the effects will be. Climate has varied naturally in the past, but today's circumstances are unique because of human influences on atmospheric composition. As we progress into the future, the magnitude of the present anthropogenic change will become overwhelmingly large compared to that of natural changes. In the absence of climate mitigation policies, the 90% probability interval for warming from 1990 to 2100 is 1.7° to 4.9°C (*19*). About half of this range is due to uncertainty in future emissions and about half is due to uncertainties in climate models (*2*, *19*), especially in their sensitivity to forcings that are complicated by feedbacks, discussed below, and in their rate of heat uptake by the oceans (*20*). Even with these uncertainties, the likely outcome is more frequent heat waves, droughts, extreme precipitation events, and related impacts (such as wild fires, heat stress, vegetation changes, and sea level rise) that will be regionally dependent.

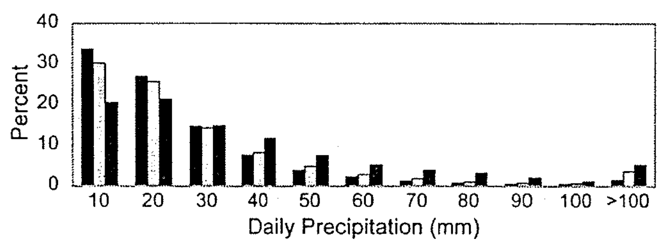

Fig. 2. Climatology of the intensity of daily precipitation as a percentage of total amount in 10 mm/day categories for different temperature regimes, based on 51, 37, and 12 worldwide stations, respectively: blue bars, –3°C to 19°C; pink bars, 19°C to 29°C; dark red bars, 29°C to 35°C. By selection, all stations have the same seasonal mean precipitation amount of 230 ± 5 mm. As temperatures and the associated water-holding capacity of the atmosphere (*15*) increase, more precipitation falls in heavy (more than 40 mm/day) to extreme (more than 100 mm/day) daily amounts.

The rate of human-induced climate change is projected to be much faster than most natural processes, certainly those prevailing over the past 10,000 years (*2*). Thresholds likely exist that, if crossed, could abruptly and perhaps almost irreversibly switch the climate to a different regime. Such rapid change is evident in past climates during a slow change in the Earth's orbit and tilt, such as the Younger Dryas cold event from ~11,500 to ~12,700 years ago (*2*), perhaps caused by freshwater discharges from melting ice sheets into the North Atlantic Ocean and a change in the ocean thermohaline circulation (*21*, *22*). The great ice sheets of Greenland and Antarctica may not be stable, because the extent to which cold-season heavier snowfall partially offsets increased melting as the climate warms remains uncertain. A combination of ocean temperature increases and ice sheet melting could systematically inundate the world's coasts by raising sea level for centuries.

Given what has happened to date and is projected in the future (*2*), substantial further climate change is guaranteed. The rate of change can be slowed, but it is unlikely to be stopped in the 21st century (*23*). Because concentrations of long-lived greenhouse gases are dominated by accumulated past emissions, it takes many decades for any change in emissions to have much effect. This means the atmosphere still has unrealized warming (estimated to be at least another 0.5°C) and that sea level rise may continue for centuries after an abatement of anthropogenic greenhouse gas emissions and the stabilization of greenhouse gas concentrations in the atmosphere.

Our understanding of the climate system is complicated by feedbacks that either amplify or damp perturbations, the most important of which involve water in various phases. As temperatures increase, the water-holding capacity of the atmosphere increases along with water vapor amounts, producing water vapor feedback. As water vapor is a strong greenhouse gas, this diminishes the loss of energy through infrared radiation to space. Currently, water vapor feedback is estimated to contribute a radiative effect from one to two times the size of the direct effect of increases in anthropogenic greenhouse gases (*24*, *25*). Precipitation-runoff feedbacks occur because more intense rains run off at the expense of soil moisture, and warming promotes rain rather than snow. These changes in turn alter the partitioning of solar radiation into sensible versus latent heating (*14*). Heat storage feedbacks include the rate at which the oceans take up heat and the currents redistribute and release it back into the atmosphere at variable later times and different locations.

Cloud feedback occurs because clouds both reflect solar radiation, causing cooling, and trap outgoing long-wave radiation, causing warming. Depending on the height, location, and the type of clouds with their related optical properties, changes in cloud amount can cause either warming or cooling. Future changes in clouds are the single biggest source of uncertainty in climate predictions. They contribute to an uncertainty in the sensitivity of models to changes in greenhouse gases, ranging from a small negative feedback, thereby slightly reducing the direct radiative effects of increases in greenhouse gases, to a doubling of the direct radiative effect of increases in greenhouse gases (*25*). Clouds and precipitation processes cannot be resolved in climate models and have to be parametrically represented (parameterized) in terms of variables that are resolved. This will continue for some time into the future, even with projected increases in computational capability (*26*).

Ice-albedo feedback occurs as increased warming diminishes snow and ice cover, making the planet darker and more receptive to absorbing incoming solar radiation, causing warming, which further melts snow and ice. This effect is greatest at high latitudes. Decreased snow cover extent has significantly contributed to the earlier onset of spring in the past few decades over northern-hemisphere high latitudes (*27*). Ice-albedo feedback is affected by changes in clouds, thus complicating the net feedback effect.

The primary tools for predicting future climate are global climate models, which are fully coupled, mathematical, computer-based models of the physics, chemistry, and biology of the atmosphere, land surface, oceans, and cryosphere and their interactions with each other and with the sun and other influences (such as volcanic eruptions). Outstanding issues in modeling include specifying forcings of the climate system; properly dealing with complex feedback processes (Fig. 3) that affect carbon, energy, and water sources, sinks and transports; and improving simulations of regional weather, especially extreme events. Today's inadequate or incomplete measurements of various forcings, with the exception of well-mixed greenhouse gases, add uncertainty when trying to simulate past and present climate. Confidence in our ability to predict future climate is dependent on our ability to use climate models to attribute past and present climate change to specific forcings. Through clever use of paleoclimate data, our ability to reconstruct past forcings should improve, but it is unlikely to provide the regional detail neces-

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CLIMATE SCIENCE 2005 MAJOR NEW DISCOVERIES

KELLY LEVIN AND JONATHAN PERSHING

INTRODUCTION

2005 was a year in which the scientific discoveries and new research on climate change confirmed the fears and concerns of the science community. The findings reported in the peer-reviewed journals last year point to an unavoidable conclusion: The physical consequences of climate change are no longer theoretical; they are real, they are here, and they can be quantified.

In this short paper, WRI reviews some of the major discoveries from the past year. Taken collectively, they suggest that the world may well have moved past a key physical tipping point.

In addition, the science tells us the effects of climate change are at a scale that adds enormous urgency not only to the efforts to prevent additional change, but equally important, to efforts to adapt to the impacts already occurring.

Finally, the science makes it clear that additional climate impacts will result even if emissions of greenhouse gases are halted immediately.

A wide body of scientific and technical literature was reviewed in the preparation of this paper, including key general science journals (*Nature* and *Science*), several technical journals (*Geophysical Research Letters*, *Annals of the Missouri Botanical Gardens*, *Ecology Letters*, *Ecology*, *Environment International*, and *Journal of Climate*) and material from key web sites and international organizations (RealScience.org, the UN's Food and Agriculture Organization, the U.S. Department of Energy, and others).

Each scientific paper is briefly described, along with the full citation to the original paper, and a short comment regarding the implications of each discovery is offered.

For ease of reading and organizational simplicity, the discussion below is separated into four sections:

- Physical climate (solar radiation, temperature increases, thermal inertia, and GHG concentrations)
- Hydrological cycle (hurricanes, glacial and snow melt, oceans, and water supply)
- Ecosystems (ecosystem services, food supplies, carbon sequestration)
- Technologies for climate change mitigation

The next major international assessment of the science of climate change, by the Intergovernmental Panel on Climate Change (IPCC), is planned for release next year. That report will address these as well as other discoveries related to the science, impacts, and potential response strategies to climate change.

However if the new scientific findings reviewed here (coupled with the overall trend of rapid increases in greenhouse gas emissions) are any indicator, they suggest the world is in both for an ominous report, and more significantly, a major shift in Earth's climate.

PHYSICAL CLIMATE (SOLAR RADIATION, TEMPERATURE INCREASES, THERMAL INERTIA, OCEAN BEHAVIOR, AND GREENHOUSE GAS CONCENTRATIONS)

Recent scientific studies confirm that human-induced climate change is leading to increases in atmospheric and ocean temperatures. Studies conducted in 2005 also note that there will be a delay in climate impacts as a result of thermal inertia. Therefore, even if our society were to halt greenhouse gas emissions today, we have already committed to substantial warming and sea-level rise in future years.

Temperature, solar radiation, thermal inertia and ocean behavior

1. *2005 Temperature Records*

   NASA's Goddard Institute for Space Studies team collected data on 2005 temperatures and found that the annual mean global temperature data for January through December was higher than the average for those months in 1998, which was the previous record-breaking warmest year.

- **NASA Goddard Institute for Space Studies Surface Temperature Analysis at data.giss.nasa.gov/gistemp/**

  The annual mean global surface temperature differs by 0.6°Celsius from the base period (1951–1980) mean, and 0.8°Celsius in the past century. After 2005 and 1998, the next warmest years are 2002 and 2003, respectively. The 2004 meteorological year follows as the subsequent warmest year.

  Record warmth in 2005 is notable, because global temperature has not received any boost from a tropical El Niño this year. The prior record year, 1998, on the contrary, was lifted 0.2°Celsius above the trend line by the strongest El Niño of the past century.

  Recent warming coincides with rapid growth of human-made greenhouse gases. Climate models show that the rate of warming is consistent with expectations.

  Implications: The observed rapid warming gives enormous urgency to discussions about how to slow greenhouse gas (GHG) emissions; models project continued increases in both GHG concentrations and, thus, global temperature unless considerable reductions are taken.

2. *Energy Imbalance*

   Using a climate model that incorporates anthropogenic greenhouse gas emissions, scientists have recently concluded that the Earth is absorbing more energy than it emits. The energy imbalance, when compared to temperature measurements, indicates a lag in atmospheric warming.

- **Hansen, James et al. "Earth's Energy Imbalance: Confirmation and Implications."** ***Science*** **308(5727): 1431–1435 (3 June 2005).** ***Science*** **Express on 28 April 2005 at www.sciencemag.org.**

  The study's results are substantiated by ocean heat content measurements and surface air temperature records over the past decade. The authors suggest that even if we were to halt changes to atmospheric composition today, we should expect to see an increase in warming of 0.6° Celsius in the future. This leads the authors to underscore the need for early action, given that ice melting and sea level rise will advance in years to come due to the climate system's inertia.

  Implications: The energy imbalance and the lag in climate response cited in Hansen's study suggests there are significant climate effects that will only reveal themselves with time. We are thus committed to considerable additional future warming from historic emissions — but also, unless we cut emissions sharply, we will see considerable additional future effects. As a result of thermal inertia, delaying action is likely to amplify change in the future.

3. *Risk of Exceeding Temperature Target of 2°Celsius Above Pre-industrial Levels*

   More than 200 scientists, government officials, and members of civil society gathered in Exeter, United Kingdom (UK) in February 2005 to discuss what constitutes — and how we can avoid — dangerous climate change. Among the noteworthy papers presented at the conference, one explored the risks of exceeding a 2°Celsius equilibrium temperature target. The author of this paper concluded that delay in action by as few as five to 10 years will increase the probability of exceeding the threshold dramatically.

- **Meinshausen, Malte. "On the Risk of Overshooting 2°C."** ***Proceedings from International Symposium on Stabilisation of Greenhouse Gas Concentrations — Avoiding Dangerous Climate Change*****, Exeter, 1–3 February 2005 at www.stabilisation2005.com/programme.html.**

  Meinshausen assigns a probability of exceeding the 2°Celsius threshold a risk of between 68% and 99% at 550 ppm CO_2 equivalence levels. However, he suggests that the risks of exceeding the threshold are reduced at lower stabilization levels. For example, at levels of 400 ppm CO_2 equivalence, the risks are significantly reduced (to 20% or less).

  Implications: According to the IPCC 2001 report, impacts associated with climate increase markedly when global temperatures rise 2°Celsius or more above today's levels. This suggests that aggressive action will be needed: current concentrations are more than 380 ppm and rising about 2ppm per year. Unfortunately, global policy is not now on course to limit concentrations to below 400 pm, the level judged "safe" in this analysis.

4. *Solar Radiation and Climate Change*

While a few regions are still experiencing global dimming due to aerosols and dust, according to two studies conducted in 2005, many areas are now witnessing some increased brightness as a result of pollution abatement. However, this brightness brings reason to worry: air pollution may have masked the effects of climate change, and additional solar brightening may hasten temperature rising.

- **Wild, Martin et al. "From Dimming to Brightening: Decadal Changes in Solar Radiation at Earth's Surface."** ***Science*** **308(5723): 847–850. 6 May 2005 at www.sciencemag.org**
- **Pinker, R. T. et al. "Do Satellites Detect Trends in Surface Solar Radiation?"** ***Science*** **308(5723): 850–854. 6 May 2005 at www.sciencemag.org**

The degree to which global dimming has shielded climate change effects is still unclear, and scientists are in the process of researching the linkage. Preliminary research conducted by Martin Wild suggests that air pollution prior to 1990 may have protected us from 50% or more of warming.

Implications: Air pollution, which blocks some amount of solar radiation, may have shielded us from climate change impacts. Because major urban areas have been successful in abating pollution (with consequent improvement in air quality), particles that block incoming solar radiation have been reduced, and, as a result, incoming solar radiation reaching the earth is stronger. Increases in incoming radiation increase the Earth's warming — and thus, climate change impacts may be augmented in the future as a result.

Ocean Behavior

1. *Human-induced Climate Change and Oceans*

The world's oceans have been warming over the past few decades. While the warming signal is not straightforward, scientists have recently concluded that the observed warming is caused by human-induced climate change, and that natural forcing, such as by solar or volcanic factors, cannot explain the phenomenon.

- **Barnett, Tim et al. "Penetration of Human-Induced Warming into the World's Oceans."** ***Science.*** **309(5732): 284–287 (8 July 2005).** ***Science*** **Express on 2 June 2005 at www.sciencemag.org**

The study demonstrates that modeling uncertainties are quite small — and preclude a simple "natural fluctuation" explanation for ocean warming. The authors thus conclude the warming is caused by human-induced climate forcing. In addition, the authors offer new confidence in climate models and suggest that global models can make reliable predictions for the next two to three decades.

Implications: Over the past decade, policymakers have called for only limited climate action based on the assumption that the science of climate change may be wrong. Those holding this view have claimed that uncertainties in the underlying physics mean that human induced changes in atmospheric composition would only lead to insignificant changes in the climate system. This study, which concludes with confidence that ocean warming is due to human-induced climate change (which is in turn caused by the release of greenhouse gas emissions), solidly refutes those skeptical views. Furthermore, the study's conclusions that oceans are warming suggests that we can expect substantial additional impacts as the climate system moves into a new global temperature equilibrium.

2. *Emissions Stabilization and Consequences for Global Mean Temperature and Sea Level Rise*

Even if we were to stop climate forcing today, the inertia in the oceans would lead to a rise in sea level and global mean temperatures for decades to come.

- **Wigley, T. M. L. "The Climate Change Commitment."** ***Science*** **307(5716): 1766–1769. 18 March 2005 at www.sciencemag.org**
- **Meehl, Gerald A. et al. "How Much More Global Warming and Sea Level Rise?"** ***Science*** **307(5716): 1769–1772. 18 March 2005 at www.sciencemag.org**

According to the Wigley study, even if we froze atmospheric composition at today's levels, the inertia in the ocean system alone could raise global mean temperatures by 2° to 6° Celsius by the year 2400 and sea levels by 25 centimeters per century until at least the year 2400. This is confirmed by independent work by Meehl et al., who conclude that if greenhouse gas levels were stabilized at 2000 levels, atmospheric temperatures would still increase by 1.1–3.5° Celsius and sea levels would rise by an additional 13–30 cm by the end of this century.

Implications: Recent scientific studies confirm that human-induced climate change is leading to rising ocean and atmospheric temperatures. These studies confirm expectations that there will be a delay in climate impacts as a result of the ocean's thermal inertia. Therefore, even if our society were to halt greenhouse gas emissions today, we have already committed to substantial warming and sea-level rise in future years. Furthermore, the longer our society waits to curtail emissions, the more significant the climate impacts we will commit to in the future. Given that emissions are not currently being capped, we are not on a track to limit either sea-level rise or temperatures even at the levels these models indicate.

3. *Slowing of the Atlantic Conveyer Belt*

A recent scientific study provides evidence that the Atlantic Ocean conveyer belt is slowing. The data suggests that the Atlantic overturning circulation is 30% slower than that of the period between 1957 and 2004, although the direct impacts of climate change to the overturning circulation have yet to be documented through observations.

- **Bryden, Harry L. et al. "Slowing of the Atlantic Meridional Overturning Circulation at 25° N." *Nature* 438: 655–657. 1 December 2005 at www.nature.com**

The analysis is part of a periodic sampling of ocean flows at 25°N latitude. The most recent surveys, undertaken in 1998 and 2004 show notable decreases in deep circulation flow. The reduction in volume of the flow is huge: the equivalent of 60 times the flow of the Amazon River.

Implications: Global ocean circulation is one mechanism that regulates temperature throughout the world; warm waters around the equator flow northward and bring heat to Northern Europe, while cool waters from the polar region flow southward. Reductions in the volume of these flows are likely to yield a corresponding reduction in the northward heat flux. Should this be sustained, it would be extremely significant: modeling experiments suggest that this kind of decrease should be associated with a decrease in ocean temperatures in the North Atlantic of up to 2°Celsius or so, and maybe 0.5°Celsius over Europe. While such changes have not yet been observed (both the North Atlantic and Europe have warmed over this time period), if the trend continues we may expect considerable changes in the temperature and climate of Europe.

Greenhouse Gas Concentrations

1. *Greenhouse Gas Levels and Climate from Ice Core Sampling*

Two scientific reports released this year have used ice core samples from East Antarctica to detect greenhouse gas cycles of the past 650,000 years.

- **Spahni, Renato et al. "Atmospheric Methane and Nitrous Oxide of the Late Pleistocene from Antarctic Ice Cores." *Science* 310(5752): 1317–1321. 25 November 2005 at www.sciencemag.org**
- **Siegenthaler, Urs et al. "Stable Carbon Cycle-Climate Relationship During the Late Pleistocene." *Science* 310(5752): 1313–1317. 25 November 2005 at www.sciencemag.org**

The ice cores, sampled and analyzed by the European Program for Ice Coring in Antarctica, reveal the long-term glacial-interglacial cycles of the climate and provide records of atmospheric carbon dioxide, methane, and nitrous oxide for the time period. The researchers note that methane and carbon dioxide levels after the Industrial Revolution remain unmatched to any record during the 650,000 years before the Revolution.

Implications: It has often been asserted that the geological record contains previous cases where CO_2 concentrations have risen to extraordinary heights — with little or no concomitant climate change. This data makes clear that we have surpassed any previous data in terms of GHG concentrations — and are, thus, in uncharted territory in terms of potential impacts and damages.

Hydrological Cycle (Hurricanes, Glacial/Snow Melt, and Water Supply)

One of the most significant impacts of climate change is predicted to be shifts in storm intensities, a rise in sea level, and increasingly rapid snow and ice melt (both from mountain glaciers, as well as in the Arctic).

Hurricanes

According to recent scientific studies, increased intensity of hurricanes can be attributed in part to climate change. In addition, scientists are now drawing a link between climate change and the first-ever South Atlantic hurricane, which occurred in Spring 2004.

1. *Hurricane Intensity and Climate Change*

   Two recent scientific findings conclude that there has been an increase in hurricane intensity and attribute this trend in part to climate change.

- **Emanuel, Kerry. "Increasing Destructiveness of Tropical Cyclones Over the Past 30 Years."** ***Nature*** **436: 686–688. 4 August 2005 at www.nature.com**
- **Webster, P. J. et al. "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment."** ***Science*** **309(5742): 1844–1846. 16 September 2005 at www.sciencemag.org**

While scientists have yet to conclude whether the number of hurricanes per year is correlated with climate change (Trenberth, Kevin. "Uncertainty in Hurricanes and Global Warming." *Science*. Volume 308. 17 June 2005 at www.sciencemag.org), these two recent studies demonstrate that there has been an increase in hurricane intensity and attribute this trend to climate change, among other factors. Emanuel developed an index based on factors associated with hurricane destructive power. It includes sea surface temperature (which has been rising in part due to climate change and is correlated with hurricane intensity), as well as interannual and interdecadal swings in storm frequency, wind shear, sub-surface ocean temperatures, and tropospheric temperatures. Emanuel coupled the projected trends for hurricane intensity with the observed trends, and concludes that the observed increase in hurricane intensity far exceeds the pace of the predicted increase; he also concludes that climate change can be expected to further increase the intensity of hurricanes in the future.

Webster et al. shed additional light on the relationship between hurricane intensity and climate change, examining the upward trend in the number of category 4 and 5 hurricanes over a 30-year period. Their findings are consistent with climate models that attribute more intense storms to higher levels of greenhouse gases, which contribute to climate change.

Implications: There has been almost a doubling of hurricane power dissipation over the period on record, and future climate change, according to these analyses, can be expected to bring a greater number of intense storms. Given damages associated with intense storms over the recent past (for example, reports by Munich Re and others indicate weather-related damages over the past 25 years at about $1.5 trillion), we will need to increase our capacity to deal with damages to coastal communities and ecosystems.

2. *First South Atlantic Hurricane*

   The first hurricane ever reported in the South Atlantic hit southern Brazil in Spring 2004:

- **Pezza, Alexandre and Simmonds, Ian. "The First South Atlantic Hurricane: Unprecedented Blocking, Low Shear, and Climate Change."** ***Geophysical Research Letters*** **32(L15712). 12 August 2005 at www.agu.org/journals/gl/**

Pezza et al. suggest that the persistence of the conditions that caused the hurricane can be attributed to climate change. Their analysis showed that the Caterina hurricane (named after Brazil's Saint Caterina State), accumulated its strength as a result of atmospheric anomalies — an unparalleled combination of wind shear and rare conditions at mid-to-high latitudes — which themselves are attributed to climate change. The authors conclude by drawing a direct link between South Atlantic hurricanes and climate change.

Implications: The expected persistence of such anomalies under a climate change future is likely to lead to increased intensity and frequency of Southern Atlantic storms. Few South American communities have experience dealing with hurricane intensity storms — suggesting that considerable effort will be required to minimize community and coastal ecosystem damages.

Glaciers and Snow Melt

Glaciers are retreating, ice sheets are melting and collapsing, and early snowmelt is augmenting warming rates. Recent scientific studies document these climate change impacts in detail and discuss implications for the future.

1. *Arctic Sea Ice Levels and Climate Change*

   NASA scientists have long been tracking Arctic sea ice, which has been significantly retreating over recent years. June, which brings about the start of the melting season, established a record low in 2005 for sea ice cover — 6 percent below average.

- **NASA Earth Observatory. "Record Low for June Arctic Sea Ice." June 2005 at earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=16978**

  While, historically, the ice has always regained coverage during the wintertime, recent years' warming has prevented such recovery. Arctic sea ice has been markedly decreased in the winter months as well as in the summer months. Following the trend set over the past few years, 2005 will likely be yet another year characterized by record low sea ice concentrations, according to NASA predictions.

  Implications: The melting of sea ice is occurring more rapidly than heretofore predicted. Ice melting leads to changes in ocean salinity, freshening ocean waters and potentially contributing to changes in thermohaline circulation (the ocean's conveyer belt effect that moves equatorial heat to the north, warming Europe). Consistent with the trend in decreased sea ice concentrations, the study's results foreshadow a future of low sea ice cover with increasing concomitant effects.

2. *Antarctic Glacial Retreat*

   A study published this year in the journal *Science* examined 244 marine glaciers in Antarctica and found that glaciers across the Antarctic Peninsula have been melting at unprecedented, accelerating rates.

- **Cook, A.J. et al. "Retreating Glacier Fronts on the Antarctic Peninsula Over the Past Half-Century." *Science* 308(5721): 541–544. 22 April 2005 at www.sciencemag.org**

  The study measured glacial cover over several decades and found that 87% of the 244 Antarctic glaciers have retreated. Cook et al. combined several research methodologies, including aerial photographs and satellite imagery, to assess the state of Antarctic Peninsula glacial ice cover.

  Implications: The study's results confirm modeling predictions that polar regions will warm at faster rates than lower latitudes. Moreover, the rate of change, as demonstrated by Cook and colleagues, is much faster than previously anticipated. As with other studies of Arctic melting, the results may, over time, lead to a fundamental change in thermohaline circulation — as well as to local faunal and floral changes as species seek to adapt to changing conditions.

3. *Ice Sheet Melting and Relation to Sea Level Rise*

   A recent scientific study of Antarctic and Greenland ice sheets suggests that current modeling efforts have potentially significant shortcomings, as they do not fully assess the positive feedback loop between ice sheet melting and sea level rise.

- **Alley, Richard B. et al. "Ice-Sheet and Sea-Level Changes." *Science* 310(5747): 456–460. 21 October 2005 at www.sciencemag.org**

  Ice sheet melting due to a warming climate may contribute further to climate change than earlier studies anticipated, as sea level rise from melting affects ocean circulation, which, in turn leads to additional climate changes. According to Alley et al., few projections fold in the potential interrelatedness of ice sheet melting, ocean circulation, and climate change. Lacking data on these relationships, scientists have not been able to assess the impacts of these feedbacks.

  Implications: Theoretical assessments suggest that one critical consequence of adding fresh water to the oceans will be a slowing in ocean circulation. A second consequence of ice melt is sea level rise — which until recently had been thought to contribute less to ocean levels than thermal expansion but now is assumed to play a more significant role. While existing model projections already suggest potentially major effects from continued climate change, the results of this study suggest that previous studies understate the consequences, as they do not take into account the full suite of ocean/ice/temperature interactions.

4. *Antarctic Peninsula's Larsen Ice Shelf Stability and Climate Change*

Since a large portion of the Larsen B ice shelf collapsed in 2002, scientists have been studying the region for clues as to why the event occurred. New results suggest a combination of factors: not only has the ice been thinning throughout the present geological era (the Holocene epoch), but human-induced climate change leading to regional Antarctic warming has also played a role in thinning and collapse.

- **Domack, Eugene et al. "Stability of the Larsen B Ice Shelf on the Antarctic Peninsula During the Holocene Epoch." *Nature* 436: 681–685. 4 August 2005 at www.nature.com**

The ice shelf collapse, some 12,500 km^2 in area, was unprecedented during the past 10,000 years. Domack et al. used a variety of paleontological and geological techniques to detect ice shelf thinning. They discovered that while there has been considerable long-term thinning in the ice over the past several thousands of years, it has been the recent warming over the Antarctic peninsula that triggered the collapse. They note that the event is unprecedented in the past 11,500 years — during which entire period the ice shelf has been quite stable.

Implications: With both models and theory predicting that the poles will warm faster than equatorial regions, we may expect increasing instability in the Antarctic ice shelf. Collapse of major ice shelves, such as the Larsen B ice shelf studied by Domack et al., can have adverse impacts to the Antarctic ecosystem, as coastal species are no longer able to survive in the changed environment. The collapse is another signal that climate is changing — and that the theory is more and more being borne out in direct observation.

5. *Land Surface Changes and Amplified Future Arctic Summer Warming*

While many scientists have long been following the pronounced summer warming in the Arctic, a recent scientific study takes Arctic research one step further by assessing the feedbacks between land surface changes due to summer warming and the implications for future summer warming. One new study shows that atmospheric warming has led to a lengthened snow-free season in arctic Alaska, which has in turn led to terrestrial changes, such as shrub and tree expansion.

- **Chapin III, F.S. et al. "Role of Land Surface Changes in Arctic Summer Warming." *Science* 310(5748): 657–660 (28 October 2005). Science Express on 22 September 2005 at www.sciencemag.org**

Chapin et al. show that land surface changes provide a positive feedback, and augments atmospheric warming by a factor of two to seven. They suggest that terrestrial transformations will increase local atmospheric warming by roughly three watts per square meter per decade (similar in magnitude to the regional heating expected over multiple decades from a doubling of atmospheric CO_2). In turn, the rate of summer warming will increase significantly, magnifying climate change impacts in Arctic communities and ecosystems. The study's authors posit that summer warming will be further amplified as a result of ongoing additional land surface changes.

Implications: Many species of arctic animals can only prosper under current conditions of ice and snow — including popular megafauna such as the polar bear and the arctic seal. Changes in vegetation as well as in temperature will reduce the aerial extent of their habitat. Increased warming will have other consequences as well: subsistence communities' livelihoods may be threatened, and many human infrastructures that rely on winter ice cover (for example, ice roads for haulage to Alaska's North Slope oil wells) may have a reduced capacity due to such changes.

Hydrological Cycles, Water Supply

Climate change is altering hydrological cycles, with long-term implications for global food availability and the viability of ecosystems. We are already seeing changes in the frequency and intensity of drought and flooding. In addition, mountain snowmelt is coming earlier due to warming temperatures, limiting water supply during peak demand season.

1. *Climate Change and Precipitation*

A study conducted this year has broad implications for future global precipitation variance, suggesting that several regional precipitation trends can already be detected and will likely increase in the future due to climate change. In particular, wet regions are increasingly experiencing higher levels of precipitation, and arid areas are witnessing reduced levels and becoming drier.

- **Dore, Mohammed H.I. "Climate Change and Changes in Global Precipitation Patterns: What Do We Know?" *Environment International* 31(8): 1167–1181 (October 2005). Available online 25 May 2005 at www.sciencedirect.com/science/journal/01604120**

  Dore compiles and reviews regional and continental levels of precipitation and is able to draw conclusions regarding rainfall patterns. He attributes the precipitation patterns and variance to climate change and ocean currents. In addition, he links precipitation variance with global food availability and states that food security will be hit hard by climate change.

  Implications: Changes in precipitation are one of the expected impacts of climate change. This study suggests the changes are already observable — and are likely to intensify with additional warming. Further changes in precipitation patterns (both in intensity and variability) will require communities increasingly to control for drought and flooding. Implications for food availability, particularly in drought or flood-prone areas, could be significant.

2. *Climate Change, Deforestation and Amazon Hydrological Cycle*

   Scientists have recently discovered that deforestation in the Amazon is leading to greater changes in the Amazon's climate and hydrological cycles than initially predicted.

- **Chagnon, F.J.F. and R.L. Bras. "Contemporary Climate Change in the Amazon." *Geophysical Research Letters* 32(L13703). 9 July 2005 at www.agu.org/journals/gl/**

  Chagnon and Bras conclude that rainfall is actually increasing over deforested areas as a result of shallow cloud levels. Deforestation thus becomes another determining factor of the region's hydrologic cycle.

  Implications: Scientists have already concluded that deforestation releases significant levels of greenhouse gases, which are stored in the forest's carbon sinks. According to many scientists, increased levels of greenhouse gases are altering global precipitation levels and variance. This study implies that deforestation by itself can also dramatically change hydrological cycles, compounding climate change effects. Given its size and role in distributing freshwater through the ecosystem, the Amazon hydrological cycle is key to global climate patterns. The study's findings suggest that the shifting patterns of rainfall and shallow clouds could have dramatic implications for the global climate.

3. *Amazon Basin and Drought*

   A study conducted this year by the Amazon Environmental Research Institute suggests that the extreme drought characterizing the Amazon Basin may have been driven by Atlantic Ocean surface warming and resultant air circulation changes. Researchers at a forest monitoring station run by the Woods Hole Research Center also state that rising sea surface temperatures in the North Atlantic could be responsible for the record drought.

- **Amazon Environmental Research Institute. "Amazon Basin experiencing extreme drought." 19 October 2005 at forests.org/articles/reader.asp?linkid=47478**

- **Hopkin, Michael. "Amazon Hit by Worst Drought for 40 Years: Warming Atlantic Linked to Both US Hurricanes and Rainforest Drought." *Nature* News. 11 October 2005 at www.nature.com**

  Warming sea surface temperatures create both low-pressure and high-pressure storm systems over the Atlantic. The low pressure systems are characteristic of the North Atlantic and bring increased precipitation to nearby regions. The high pressure systems, however, hold less rainwater and concentrate over the South Atlantic, leading to lower precipitation levels in regions like the Amazon. The current drought is considered the most severe in the last half century and has brought devastation to many local communities and ecosystems in the Amazon.

  Implications: Increasing greenhouse gas concentrations and resulting global temperature increases may lead to even more pronounced and lengthy periods of drought in the Amazon. Not only will the Amazon's ecosystem services, population and biodiversity be negatively impacted, but the rainforest's capacity to sequester carbon may also be compromised.

4. *Climate Change and Western North American Water Supply*

   Scientists Iris Stewart and colleagues examined snowmelt in western North American streams and suggest that climate fluctuations are driving changes in the timing of snowmelt, which is increasingly becoming triggered earlier in the season.

- **Stewart, Iris T. et al. "Changes Toward Earlier Streamflow Timing Across Western North America." *Journal of Climate* 18(8): 1136–1155. April 2005 at ams.allenpress.com/amsonline/?request=get-toc&issn=1520-0442&volume=18&issue=8**

  The scientists examined streamflow from 1948 through 2002 of more than 300 stream systems and provide evidence that the early onset of snowmelt is characteristic of a much larger portion of the region's streams than initially anticipated. Of the snowmelt-dominated gauges, which totaled 241 in number, two-thirds had an early spring onset date of more than three days.

  Implications: Snowmelt supplies water to western North American rivers and will impact many communities (e.g. drinking water availability, hydroelectric utilities, and agricultural lands will be affected) and ecosystems that rely on these water sources. Early melting may lead not only to increased intensity of spring-time flooding, but also of summer droughts when meltwater is not available at all.

5. *Climate Change Impacts on Water Availability in Snow-Dominated Regions*

   A recent scientific study published in the journal *Nature* predicts that climate change will bring devastating impacts to communities that obtain water from melting glaciers and snow packs.

- **Barnett, T. P. et al. "Potential Impacts of a Warming Climate on Water Availability in Snow-Dominated Regions." *Nature* 438: 303-309. 17 November 2005 at www.nature.com**

  Climate change is affecting hydrological cycles. One consequence is that snow and ice levels have been reduced; another is that snowmelt is occurring earlier in the spring season. Many regions lack the capacity to store winter and spring run-off for later in the season, when it is needed to meet peak summer demand. The authors review regional impacts in the Western USA, the Rhine River valley in Europe, the Hindu-Kush region in Asia, and the South American Andes. As one example, they cite Peruvian glaciers, where there has already been a 25% reduction in ice volume over the last thirty years, and where water resources will be substantially constrained in the absence of the glaciers. The authors conclude that the problem is increasingly urgent, indicating their expectations that water availability will dramatically decrease over the coming years.

  Implications: More than one-sixth of the global population lives in regions that depend on snow and glaciers for water supply. With snow, ice and glacial melting from climate change, future water availability will be compromised, which could lead to a loss of potable water, population displacement, significant agricultural losses, and massive ecosystem degradation.

Ecosystems and Ecosystem Services

Climate change is taking its toll on ecosystems and the services that humans derive from them. Species are already migrating out of historic ranges to cooler climates. Habitats are becoming reduced as a result of temperature increases. Food chains have been dramatically altered, as species fail to adapt to climate change impacts. Further alterations in ecosystem provisioning services, including wood products, drinking water supply, and soil productivity can be expected as climate continues to change.

Ecosystem Effects

Entire ecosystems (ecological systems including interlinked fauna, flora and the physical framework in which they live) are being affected by climate change. Plants and animals associated with certain geographic regions are moving — or dying. Observed changes are already significant; future changes are expected to be even more fundamental as species adapt to changing climatic conditions.

1. *African Plant Diversity and Climate Change*

   A recent scientific study exploring climate change impacts on sub-Saharan African plant species predicts that climate change will trigger species migration and lead to habitat reduction.

- **McClean, Colin J. et al. "African Plant Diversity and Climate Change." *Annals of the Missouri Botanical Garden* 92(2): 139–152. July 2005 at apt.allenpress.com/aptonline/?request=get-toc&issn=0026-6493&volume=092&issue=02**

The authors examined over 5,000 African plant species in climate models and predict that 81%–97% of the plant species' suitable habitats will decrease in size or shift due to climate change. By 2085, between 25% and 42% of the species' habitats are expected to be lost altogether.

Implications: While these models are only a preliminary step in assessing climate change impacts to sub-Saharan African plant diversity, they do provide a clear indication of the vulnerability of plant species in Africa to climate change. Ecosystems services that rely on sub-Saharan African plant diversity, including indigenous foods, as well as both locally used and potentially exotic plant-based medicines, are likely to be adversely impacted. It must be noted that their study also assumes that shifting species will be able to move — and not have migration pathways blocked by human development, or other geographic features. If such assumptions are not borne out, the overall decline could be even more severe.

2. *Species' Ranges and Climate Change*

A recent study of 16 Spanish butterfly species documents a move upward in elevation as a result of temperature rise.

- **Wilson, Robert et al. "Changes to the Elevational Limits and Extent of Species Ranges Associated with Climate Change." *Ecology Letters* 8(11): 1138. November 2005 at www.blackwell-synergy.com/toc/ele/8/11?cookieSet=1**

While models have projected that species are likely to move upwards in elevation as a result of temperature rise in the future, scientists have recently documented that the shift is already occurring. The 16 butterfly species studied in central Spain have shifted their ranges by 212 meters (about 700 feet) in elevation during the last 30 years. The area has seen an increase in 1.3°Celsius mean annual temperature. The scientists project that the species' habitat has already decreased by one-third and is likely to decrease by 50–80% during the next 100 years if climate change is left unabated.

Implications: The results suggest that climate change is already causing species' range shifts and habitat loss with long-term implications for species' survivability. Moreover, recent scientific studies (including Thomas, J.A. "Comparative Losses of British Butterflies, Birds, and Plants and the Global Extinction Crisis." *Science*. Volume 303. 19 March 2004 at www.sciencemag.org) have suggested that butterflies act as indicator species and signal early warnings — much like a canary in a coal mine. This species characteristic supports one of the conclusions from Wilson's study that more widespread ecosystem loss is already underway, and will likely become more severe in the future.

3. *Climate Change and Antarctic Fur Seals*

Scientists engaged in a 20-year study of Antarctic fur seal pups have found that the increased monthly average sea surface temperature, which they link to climate change, can explain the recent reductions in pup production.

- **Forcada, Jaume et al. "The Effects of Global Climate Variability in Pup Production of Antarctic Fur Seals." *Ecology* 86(9): 2408–2417. 25 January 2005 at www.esajournals.org/esaonline/?request=search-simple**

The authors argue that anomalies in the sea surface temperature likely caused a reduction in available prey populations of krill (the base of the seal food chain). Resulting undernourishment has in turn significantly reduced the breeding potential of Antarctic fur seal females. Thus, a 20-year trend of increased monthly average sea surface temperature, driven by climate change, can explain the recent reductions in seal pup production.

Implications: This study demonstrates the potential for climate change to severely impact marine ecosystems throughout the entire food chain. While no specific studies have yet been undertaken, it may be anticipated that, by extension, reductions in fur seal populations will in turn negatively impact their own predators, including leopard seals and killer whales. Furthermore, it demonstrates that indirect effects quite far down the animal food chain can have devastating effects at the top of the food chain and in large and often already threatened megafauna.

4. *Climate Change and Distribution of Marine Fish Populations*

Sea temperature rise is causing fish species in the North Sea to shift their ranges northward in latitude and/or deeper to find colder waters. The North Sea waters have warmed by 1.1°Celsius over the past 30 years.

- **Perry, Allison L. et al. "Climate Change and Distribution Shifts in Marine Fishes."** ***Science*** **308(5730): 1912–1915 (24 June 2005).** ***Science*** **Express on 12 May 2005 at www.sciencemag.org**

Of the 36 species examined in the North Sea (including exploited and non-exploited species), two-thirds were found to be migrating to cooler waters. The "center" of species populations moved from nearly 50 km to more than 400 km north, while southern boundaries moved from over 100 km to more than 800 km north. Species that shifted their distributions the most were smaller and had faster life cycles than those species that did not shift. Because species are shifting at different rates and amounts, the authors expect their results to have implications for commercial fisheries; some of the northern waters to which fish are migrating are already among the most over-fished in the world.

Implications: Changes in North Sea fisheries, already under stress from over-fishing, are likely to accelerate with climate change. Fisheries may need to shift to smaller and more adaptable species, as the effects of climate change continue to disrupt marine ecosystems, and as fish populations depart for cooler waters and interact with new marine species. On economic grounds alone, this could have huge implications: the North Sea fishery is valued at billions of dollars a year. Of equal significance is the clear indication that climate change has already begun to interfere with large-scale marine habitats.

5. *Implications of Warming on Plant and Animal Species*

Scientists have recently discovered that the shift in global temperatures of 5° to 10° Celsius at the beginning of the Eocene Epoch (roughly 55.8 million years ago) caused "large and rapid" shifts in the range as well as the morphology of a variety of plants.

- **Wing, Scott L. et al. "Transient Floral Change and Rapid Global Warming at the Paleocene-Eocene Boundary."** ***Science*** **310(5750): 993–996. 11 November 2005 at www.sciencemag.org**

The authors state that these ancient climate shifts mirror those projected over the next century as greenhouse gas emissions lead to rapid global warming. They conclude that a similar level of change in the range of plant species can be expected as human-induced climate change proceeds.

Implications: Geologically, periods of rapid temperature change have been associated with mass extinctions, including of marine and terrestrial organisms. While temperature changes of 5° to 10° Celsius are at the upper end of the range of the global average increase projected over the next century, they are consistent with expected temperature changes in higher latitudes. The observation that ancient flora shifts were quite rapid, and that species migrated both across continents and within continents, suggests a similar pattern may be observed today, although human activities — including urban features and agriculture — may block continent-scale migrations. It thus seems likely that ecosystems will be disrupted as species both seek to move and decline in the face of climatic change.

6. *Ocean Acidification, Marine Organisms, and Climate Change*

Two scientific studies published this year signal that the oceans are getting more acidic and that marine organisms' ability to survive will be compromised.

- **"Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide." The Royal Society. 30 June 2005 (Ref 12/05). PDF available at www.royalsoc.ac.uk/displaypagedoc.asp?id=13539**
- **Orr, James C. et al. "Anthropogenic Ocean Acidification Over the Twenty-First Century and Its Impact on Calcifying Organisms."** ***Nature*** **437: 681–686. 29 September 2005 at www.nature.com; Parks, Noreen. "Ocean Acidification Bad for Shells and Reefs."** ***Science*****. 28 September 2005 at sciencenow.sciencemag.org**

The Royal Society paper establishes that oceans are absorbing carbon dioxide from the atmosphere, resulting in ocean acidification. The study states that, in the last two centuries, oceans have absorbed roughly half of the amount of CO_2 emitted by fossil fuel use and cement production. This assimilation of carbon dioxide has caused ocean pH to be reduced as hydrogen ion concentrations increase.

Orr et al. conclude that higher ocean acidity will be devastating to the marine environment within a short period of time — within tens of years instead of hundreds of years. Basing analyses on 13 global carbon models assuming "business-as-usual" trends in greenhouse gas emissions, their conclusions are that the oceans will be undersaturated in calcium carbonate: leading to increasing difficulty for shelled organisms to create skeletons and shells. By 2050, with increasing CO_2 concentrations and increased acidity, the problem will be severe in the polar waters of the Southern Ocean. By 2100, all of the Southern Ocean and the sub-Arctic Pacific Ocean levels will be undersaturated with calcium carbonate.

Implications: Acidification of the oceans will likely wreak havoc on marine species and entire ecosystems. Given that the oceans have already absorbed a substantial amount of carbon dioxide, we have already committed to an irreversible amount of ocean acidification. As a result, we will likely see additional stress on coral reefs (already under threat due to ocean warming); other fish and aquatic organisms may be stressed as well. It is likely that rebalancing the ocean pH will take thousands — or even hundreds of thousands of years.

Ecosystem Services

Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. With climate change, we can expect processes and services to change – often for the worse. Droughts, floods, and changing disease and pest vectors will all contribute to the reduction, leading to loss of food as well as other economic benefits.

1. *Declining European Ecosystem Services*

"Ecosystem services" are the conversion of natural assets — such as trees, snow cover, and soil fertility — into valuable benefits such as wood products, winter tourism, and arable land. A scientific study conducted in Europe this year states that climate change will alter — usually for the worse — the supply of European ecosystem services over the next century.

- **Schröter, Dagmar et al. "Ecosystem Service Supply and Vulnerability to Global Change in Europe."** ***Science*** **310(5752): 1333–1337 (25 November 2005). Science Express on 27 October 2005 at www.sciencemag.org**

While climate change will result in enhancements of some ecosystem services, a large portion will be adversely impacted because of drought, reduced soil fertility, fire, and other climate change-driven factors. Thus, Europe can expect a decline in arable land, a decline in Mediterranean forested areas (although there will be an overall increase in European forest), a decline in the terrestrial carbon sink and soil fertility, and an increase in the numbers of basins with water scarcity. This will all increase biological impoverishment, and lead to a significant decline in mountain tourism. While the study suggests all of Europe will be affected, its primary focus was on the southern portion around the Mediterranean.

Implications: While this study assessed ecosystem services only in Europe, the consequences are likely applicable to ecosystem services across the globe. Furthermore, other parts of the world with lower levels of economic development and poorer infrastructure (including in particular those countries that primarily rely on agriculture or fiber for their economic well-being) are less likely to be able to cope with declining services than Europe.

2. *Climate Change and the World's Food Supply*

A study conducted this year by the United Nations Food and Agriculture Organization (FAO) and the International Institute of Applied Systems Analysis (IIASA) reveals that climate change will significantly impact the global food supply.

- **Food and Agriculture Organization of the United Nations (FAO). "Impact of Climate Change, Pests and Diseases on Food Security and Poverty Reduction."** ***Special event background document for the 31st Session of the Committee on World Food Security.*** **Rome. 23–26 May 2005 at www.fao.org/clim/default.htm. PDF available at www.fao.org/clim/docs/CFS/CFS.pdf; MS PowerPoint available at www.fao.org/clim/docs/CFS/Presen.htm.**

The study quantified crop damages using spatial soil and climate data and then overlaid projections for productivity potential under a changed climate. The results project a loss of 11% of arable land in the developing world due to climate change, including a loss of cereal production in 65 developing countries (for these countries, the loss equates to roughly 16% of agricultural GDP in 1995 dollars). The study suggested that some of the losses would be offset: "new" land available at high latitudes could become available in Russia, Northern Europe, and North America. However, the distributional effects would, overall, be quite negative.

Implications: Not only will food security be threatened by climate change impacts, but the agricultural GDP loss will also result in economic devastation for many developing countries. The developing world already has to contend with food shortages as a result of invasive species, inefficient food distribution, lack of arable land, and other factors, and climate change presents yet another factor that wreaks havoc on food supply. Climate change, in additional to exacerbating these effects, may also lead to food shortages and trigger social unrest, as well as accelerate malnutrition and disease. While overall food production may not be threatened, those least able to cope will have another cost: food imports from the North.

3. *Carbon Sequestration and Rising Atmospheric Carbon Dioxide Levels*

A 2005 study suggests that rising atmospheric CO_2 will ultimately lead to reduced carbon sequestration through trees' roots in forest soil. Therefore, as CO_2 levels increase in the atmosphere, forests will not be able to perform their role as carbon sinks as well as they do under lower concentrations — in turn, increasing the level of CO_2 that will stay in the atmosphere and exacerbate global warming.

- **Heath, James et al. "Rising Atmospheric CO_2 Reduces Sequestration of Root-Derived Soil Carbon." *Science* 309(5741): 1711–1713. 9 September 2005 at www.sciencemag.org**

The authors conclude that while increased levels of atmospheric CO_2 leads to increased tree growth, associated increases in microbial respiration lead to a decreasing quantity of CO_2 being sequestered through the trees' roots into the forest soil. Observed reductions were approximately 40%. While the study examined only a small sample, the authors believe the process would hold at large scale, and suggests that annual carbon sequestration through sinks may be significantly reduced in the future as atmospheric carbon dioxide levels rise.

Implications: The study's findings imply that projections of carbon sequestration are likely optimistic. If forests are not able to sequester carbon at the rates anticipated, global warming is likely to proceed at a much more rapid rate than anticipated. Furthermore, the process seems to create a positive feedback loop: the higher the atmospheric levels of CO_2, the less soils absorb — and therefore, the more rapidly atmospheric levels rise. Thus, not only may efforts to control global GHG concentrations through forest carbon sequestration be limited, but we may need to revise upward our expectations of the rate of global climate change.

Climate Change Mitigation Technologies

Several technological breakthroughs have occurred in 2005, which could reduce costs and ease the transition to a reduced carbon economy. These technologies run the gamut from biofuel technology advancements to fuel cell improvements to hydrogen energy innovations. Several of the new developments from 2005 are described here.

1. *Waste CO_2 from Ethanol Plant Used for Enhanced Oil Recovery*

A project funded by the U.S. Department of Energy made a technological breakthrough this year for CO_2 use in enhanced oil recovery.

- **National Energy Technology Laboratory. "CO_2 Injection Boosts Oil Recovery, Captures Emissions: DOE-Funded Watershed Project in Kansas Demonstrates Technology." 3 January 2005 at www.netl.doe.gov/publications/press/2005/tl_kansas_co2.html**

The project recovered CO_2 byproducts from ethanol production and recycled them in an enhanced oil recovery project in central Kansas. The Department of Energy states a single plant could both provide injection fluid to assist in the production of five million oil barrels a year for 25 years, as well as sequester 1.5 million tons of CO_2.

Implications: Enhancing the efficiency of oil recovery directly increases supply. While 5 million barrels is a tiny share of annual US demand, if this technology were applied on a larger scale, the additional supply could have implications for oil imports and prices.

On the sequestration side, while questions remain about long-term monitoring of geologically stored carbon, the benefits of avoiding its release into the atmosphere are significant. Finally, the process is a net economic winner: according to DOE, if all ethanol plants' waste CO_2 were sequestered by enhanced oil recovery projects, the benefits could equate to US \$88 million over a decade. Such calculations do not even include the cost of avoided climate change — with extremely high values.

2. *Nanotechnology Increasing Efficiency of Solar Cells*

A recent study by scientists at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) demonstrates that solar cells can be made more efficient through the application of nanotechnology. DOE researchers state that "quantum dots" can convert more than 65 percent of solar energy into electricity, which could roughly double existing solar cell efficiency.

- **National Renewable Energy Laboratory. "Quantum Dot Materials Can Reduce Heat, Boost Electrical Output." 23 May 2005 at www.nrel.gov/news/press/2005/1805_quantum_dot.html; *Nano Letters* at http://pubs3.acs.org/acs/journals/toc.page?incoden=nalefd**

Quantum dots, also called "nanocrystals," can produce more electricity than solar cells. While solar cells can convert one photon of solar energy to one electron (with the rest being lost as thermal byproduct), quantum dots can reduce heat waste and convert up to three electrons per sunlight photon.

Implications: The Laboratory's research team suggests that quantum dots could make solar energy more efficient and cost-effective, critical if solar technology is to replace coal or gas as a power source at competitive market rates. In addition, the researchers have suggested that the technology could be applied in the future to photoelectrochemical cells, creating a renewable method for generating hydrogen — which might be used in place of gasoline as a mobile fuel source as well as a stationary source of electricity.

3. *Solar Technology and Hydrogen Creation*

Scientists from Weizmann Institute of Science in Israel have recently discovered a method to extract zinc metal using solar power, which in turn can then be used to produce hydrogen.

- **Peplow, M. "Sunlight used to smelt zinc: Solar technique could lead to cleaner, cheaper hydrogen." *Nature News*. 4 August 2005 at www.nature.com/news/2005/050801/full/050801-11.html**

The researchers focused an intense beam of sunlight, created with more than 60 mirrors, onto zinc oxide and charcoal. Zinc powder is then created, which can in turn be used to produce hydrogen, released from water when poured over the powder. The process is not completely carbon free, as the charcoal releases carbon monoxide, which will convert to atmospheric CO_2. However, the Institute claims that if the technology were applied to a larger industrial project, the carbon monoxide could be used to create more hydrogen. In an effort to reduce the carbon byproducts, the researchers aim to explore whether agricultural waste can be used in lieu of charcoal.

Implications: Hydrogen is a clean fuel source that can be used in fuel cells, power vehicles, and generate heat and electricity. However, hydrogen gas does not exist in a natural form that can be used and captured. Thus, its use is dependent on extracting it from compounds that contain hydrogen. The production process can be energy and carbon intensive. If researchers are successful, the hydrogen production process could become more climate friendly — and even cost-effective. In addition, ongoing research may succeed in developing a process that could use solar technology for hydrogen production in vehicles — eliminating the need to develop a new infrastructure to deliver hydrogen to vehicles.

4. *Fuel Cell Technology Advancement*

Scientists from Virginia Polytechnic Institute and State University have recently developed an innovative electronic technology that makes fuel cells more efficient and could reduce their size and costs.

- **National Energy Technology Laboratory. "New Electronic Technology Advances Fuel Cell Development: University Seeks Patent, Shares Technology With Partners in DOE's SECA Program." 9 February 2005 at www.netl.doe.gov/publications/press/2005/tl_vatech_seca.html**

The technology converts direct current (DC) voltage into alternating current (AC) with appreciable gains in efficiency. According to the researchers, a 1 percent increase in efficiency can cut costs by $5–$10 per kilowatt. Such efficiency gains would eliminate large, expensive additional converters and/or capacitors, thereby reducing fuel cell system size and costs.

Implications: The technology will make fuel cells more cost-effective, smaller, and more efficient, with implications for deployment on a larger scale. If successful, this project will promote the creation of fuel cells that are attractive to residential and commercial electricity markets, as well as transportation and utility sectors.

5. *Novel Catalytic Process for Biodiesel*

Researchers at the University of Wisconsin have recently developed a new catalytic process that can convert almost any type of plant matter into fuel.

- **Huber, G.W. "Production of Liquid Alkanes by Aqueous-phase Processing of Biomass-Derived Carbohydrates" *Science* 308(5727): 1446-1450. 3 June 2005 at www.sciencemag.org and www.cnn.com/2005/TECH/06/07/biofuel.vision/**

Traditional biofuels, such as ethanol, rely on the fatty acid portion of the plant, which only comprises approximately 10 percent of plant mass. With the new catalytic process, agricultural waste could be transformed into biofuels more readily. In addition, the advanced process produces 2.2 units of energy for every unit used, and is more efficient than existing biofuels (which produce half of that amount of energy per unit used).

Implications: The innovative catalytic reactor is not only more efficient, but could also cut down on agricultural waste and reduce the need to convert lands into biofuel stocks. Biofuels are a cleaner alternative to fossil fuels and create farming jobs and income. In addition, sustainably grown crops release no CO_2 over their lifetime.

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- *To reverse damage to ecosystems.* We protect the capacity of ecosystems to sustain life and prosperity.
- *To expand participation in environmental decisions.* We collaborate with partners worldwide to increase people's access to information and influence over decisions about natural resources.
- *To avert dangerous climate change.* We promote public and private action to ensure a safe climate and sound world economy.
- *To increase prosperity while improving the environment.* We challenge the private sector to grow by improving environmental and community well-being.

In all of our policy research and work with institutions, WRI tries to build bridges between ideas and actions, meshing the insights of scientific research, economic and institutional analyses, and practical experience with the need for open and participatory decision-making.

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